Cold dust in galaxies near and far

Observational results from SCUBA to Herschel and Planck

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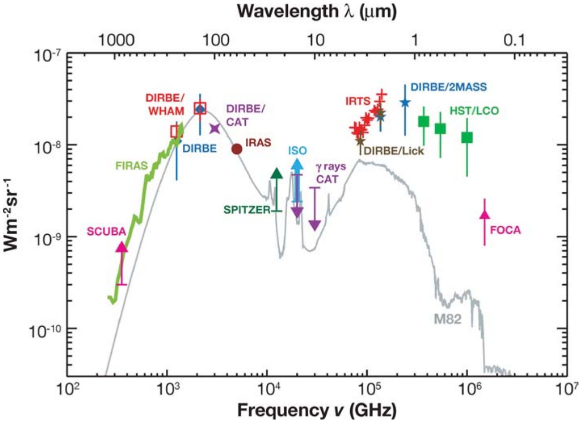
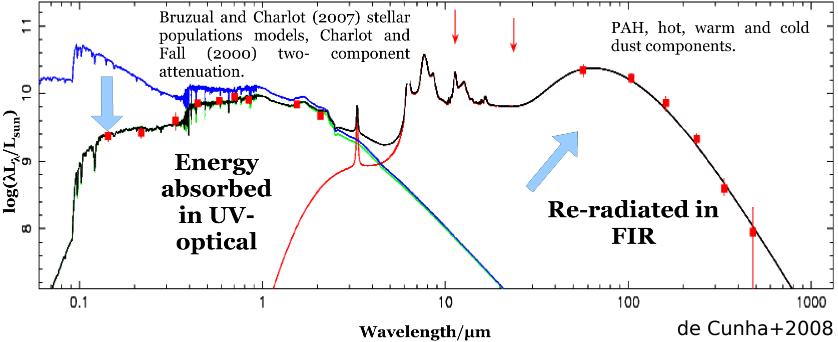
SFIG Group Activity, 2012-12-21

Nearly 50% radiation information come from dust emission



Cosmic Infrared Background radiation: 50% dust emission. (Lagache+2005)

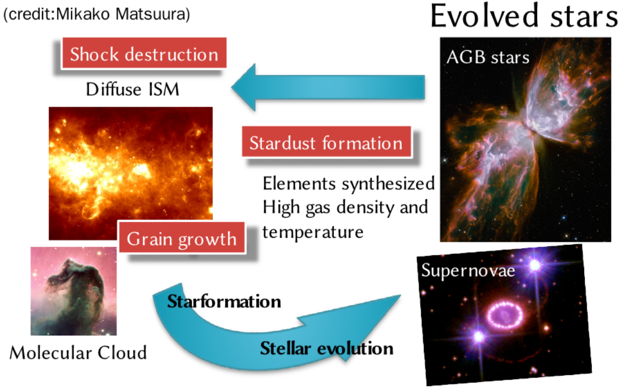
SED of an ordinary galaxy - a model view



de Cunha+2008

- Dust extinction & emission ⇒ Define the SED shape
- Galaxy metallicity⇒ Locked in dust content

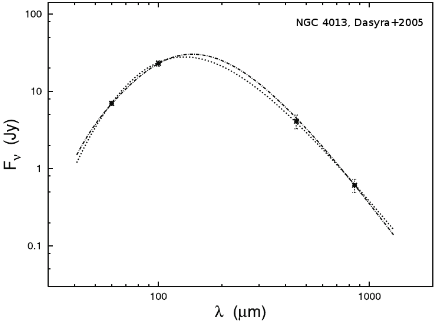
The Life cycle of interstellar dust



- ISM life-cycle: gas content, metallicity, ...
- Dust production, destruction and the origin (especially at high-z)?
- Galaxy evolution: dust play an important role!

How to study the dust content?

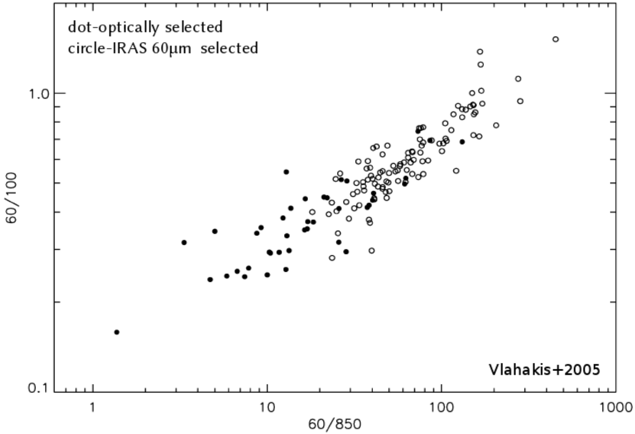
From its radiation! - Graybody emission



$$S_\nu = Q_{em}(\frac{\nu}{\nu_0})^\beta B(\nu, T)$$

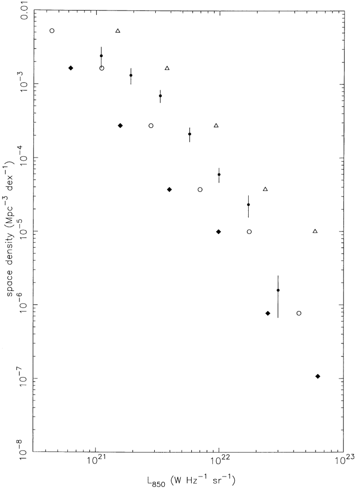
- A modified planck function with Single temperature component
- Sensitive to T_d for $S_\nu \propto T_d^{4+\beta} \Rightarrow$ some colder dust will easily be omitted

IRAS may miss a population of cold dust!



BGS Sample bias

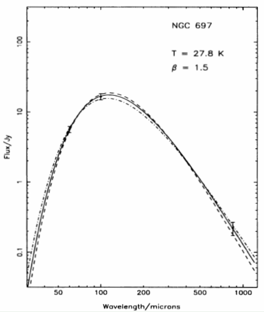
IRAS may miss a population of cold dust!



- The measured 850 μm luminosity function: solid dot
- Extrapolations of the 60 μm luminosity function using fixed parameters
    - triangles: $\beta = 2$, $T_d = 24K$
    - diamonds: $\beta = 1.5$, $T_d = 38K$
    - circles: $\beta = 1$, $T_d = 45K$
- 60 μm sources are different from the submm-detected sources!
- Something must be missing!

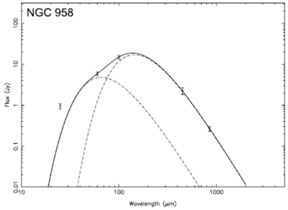
A possibility of two components model

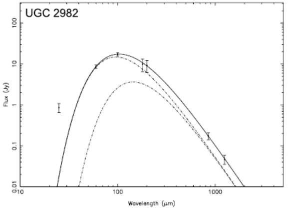
Single component



Dunne, L.+2000

Double components





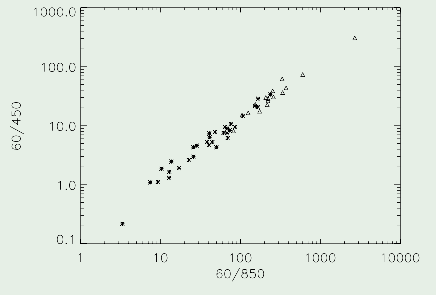
Dunne, L.+2011

- $S_\nu = N_w \times \nu^\beta B(\nu, T_w) + N_C \times \nu^\beta B(\nu, T_c)$.
- The distribution of β shifts to higher values, and there comes a very cold component.
- $60\,\mu m$ by IRAS survey can not detected this.

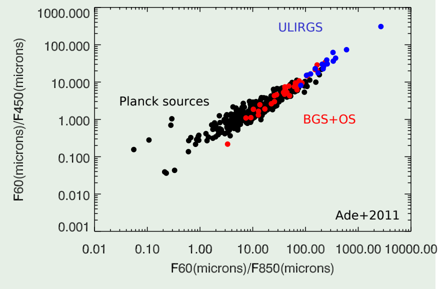
Is this model right?

A tight correlation was found between 450 μm and 850 μm

Clements+2010



Ade+2011



Emissivity index-β is the key to the question

Previous theory model works

- Mixture of silicate & graphite: $\beta = 2$ (*Drane & Lee 1984*)
- A certain types of amorphous silicates: $\beta > 1.5$, depending on T_d (*Agladze+1996*)
- Amorphous carbon: $\beta \sim 1$, graphitic grains: $\beta = 2$ (*Mennella+1995*)

The results may differ with the dust material, environmental temperature, and so on.

Previous observations

- $\beta \in [1.5, 2]$, and 2 is better. (*Braine+1997; Alton+1998; Bianchi+1998; Fraguer+1999*)

This maybe in the large-scale of the dust around stars contribute little to the observation.

Is this model right?

Fact

The theory tells us :

$$\frac{S_{450}}{S_{850}} = (\frac{\nu_{450}}{\nu_{850}})^{\beta} \times \frac{B(\nu_{450}, T_d)}{B(\nu_{850}, T_d)}$$

Deduction

The real β and T_d must have a small range.

Model Test

Then assume the two parameters to be a Gaussian or uniform distribution.

Cont'd

The models, Dunne+2001

Model	T_w (K)	T_c (K)	β	$N_c N_w$
1	Uni 25–65	–	Uni 1–2	–
2	Gau $\mu = 35.7$, $\sigma = 5.3$	–	Gau $\mu = 1.3$, $\sigma = 0.2$	–
3	Uni 30–55	Gau $\mu = 20$, $\sigma = 2.5$	2	Uni 1–100
4	Uni 30–55	18	2	Uni 1–100
5	Uni 30–55	Uni 15–25	1.5	Uni 1–100
6	Uni 30–55	Gau $\mu = 20$, $\sigma = 2.5$	Uni 1.5–2.0	Uni 1–100
7*CO	Uni 30–55	Gau $\mu = 20$, $\sigma = 2.5$	2	Uni 1–100

Note: The range of the values are taken from Dunne+2000.

$\beta = 2$ is preferred!

The test results, Dunne+2001

(1) Model	(2) Slope	(3) Int.	(4) $\sigma_{450/850}$	(5) $\langle S_{60}/S_{450}\rangle$	(6) KS	(7) $\langle S_{60}/S_{850}\rangle$	(8) KS	(9) $\langle S_{450}/S_{850}\rangle$	(10) KS
Data	1.01 ± 0.03	-0.909 ± 0.045	$1.6^{+0.42}_{-0.24}$	13.9 ± 2.1		104 ± 14		7.90 ± 0.26	
1	0.915	−0.684	2.67	64.6	0.52	574	0.49	8.13	0.15
	3.2σ	5σ	2.5e−4		2.4e−9		1.9e−8		0.33
2	0.924	−0.680	2.01	12.9	0.1	89.9	0.13	6.80	0.32
	2.9σ	5.1σ	0.079		0.83		0.51		5e−4
3	0.993	−0.910	2.36	14.6	0.16	124.4	0.09	8.72	0.23
	0.6σ	0.02σ	4.1e−3		0.26		0.89		0.03
4	0.987	−0.881	2.22	15.9	0.18	133.2	0.14	8.34	0.17
	0.8σ	0.6σ	0.0137		0.18		0.46		0.23
5	0.992	−0.774	1.73	5.5	0.5	34.2	0.55	6.32	0.42
	0.6σ	3.0σ	0.521		8.7e−9		2e−10		2e−6
6	0.970	−0.808	2.14	9.0	0.33	68.3	0.33	7.47	0.20
	1.3σ	2.2σ	0.026		4.3e−4		5.7e−4		0.089
$7^{*\mathrm{CO}}$	0.992	−0.869	2.15	14.5	0.16	113.3	0.13	7.92	0.12
	0.6σ	0.9σ	0.022		0.26		0.56		0.69

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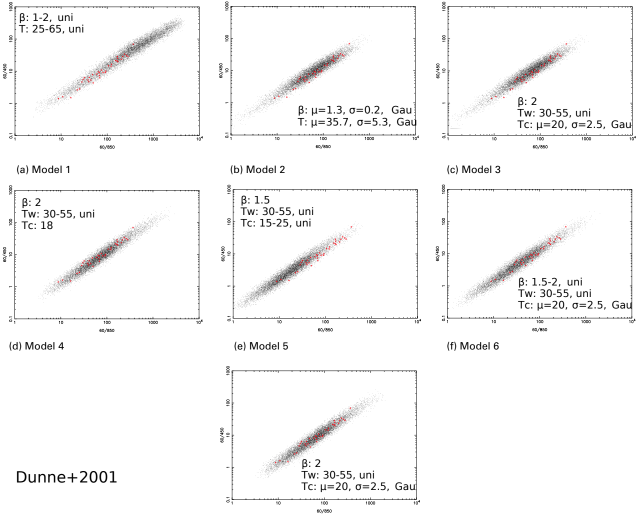


(a) Model 1 (b) Model 2 (c) Model 3

(d) Model 4 (e) Model 5 (f) Model 6

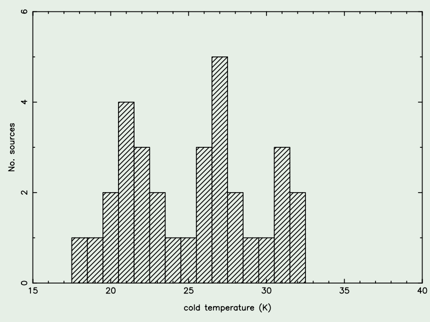
(g) Model 7

Dunne+2001

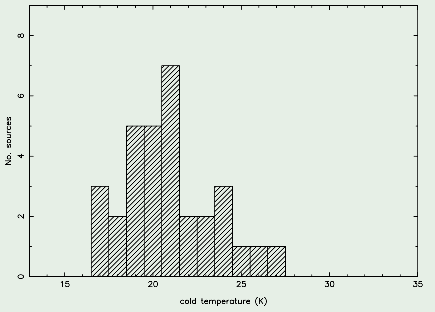
Cold component temperature distribution

Single Gaussian distribution seems reasonable than a multi-peak

free paremeter, Dunne+2001



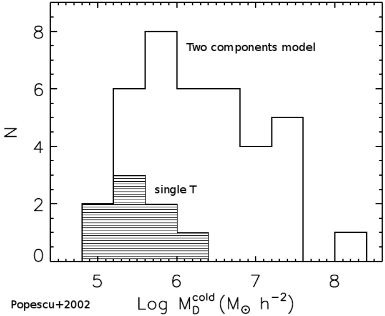
fixed to 2, Dunne+2001



Observations support two components model

- Dust SEDs in most of the local galaxies detected by Planck prefer two components model. (Ade+2011)
- The gas to dust ratio using one component model predict a 2 times higher value than MW.(Dunne+2001, Vlahakis+2005)

$$M_d = \frac{S_{850} D^2}{\kappa_d(\nu) B(\nu, T_d)}$$



Popescu+2002

Other support

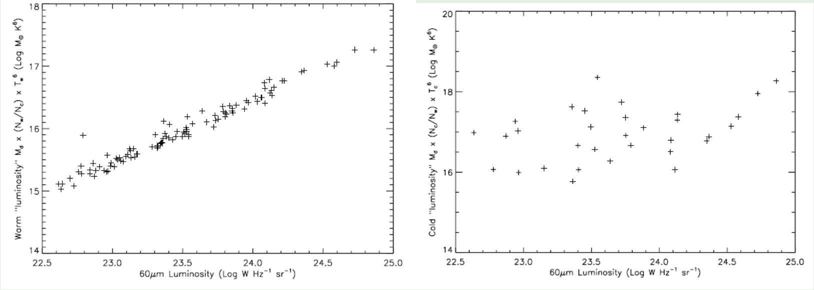
- And there are some other individual observations support this scenario in different type of galaxies.
  - NGC 7331 (Alton+2001)
  - Late-type in Virgo cluster (Popescu+2002)
  - Planck detected Local Galaxies (Ade+2011)
  - ...

A recall of IRAS biased view

There may be a group of galaxies with faint 60-μm flux and rich in cold dust which have strong submm emission being missed by IRAS

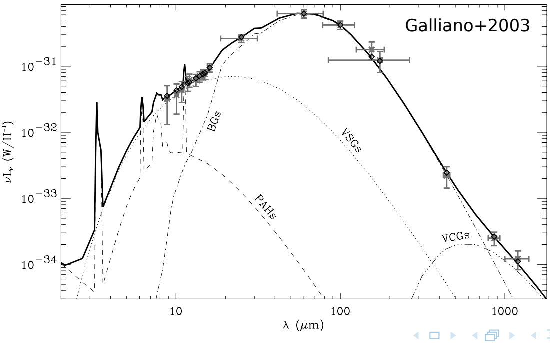
If using two components model...

It was found that the cold component has no correlation to the IRAS luminosity while the warm luminosity($M_d \times (N_w/N_c) \times T_w^6$) has a strong correlation. (Dunne+2001)



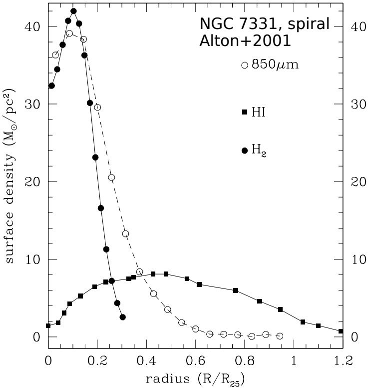
What's the heating sources?

- Warm: Strong star forming region, associated with molecular gas.
- Cold: Older stellar population ($T_{eq} = ISRF^{1/5}$) and the OB star leaks, mostly associated with HI (atomic gas).
  - The active star-forming region may not be the reason of the varying temperature, because they are local and dusty

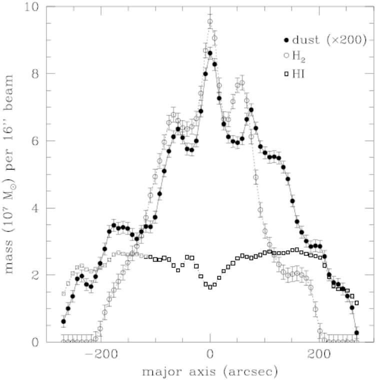


The mass correlation between dust and gas

We can find a good spatial correlation along the major axis.



NGC7331, Alton+2001



NGC 891, Alton+2000

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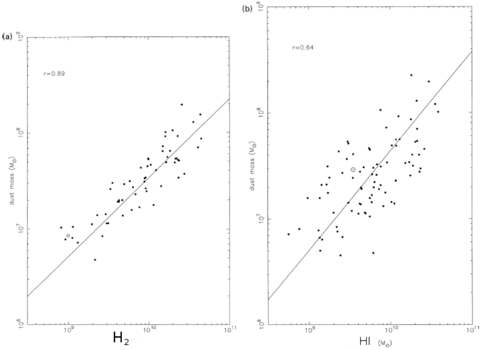
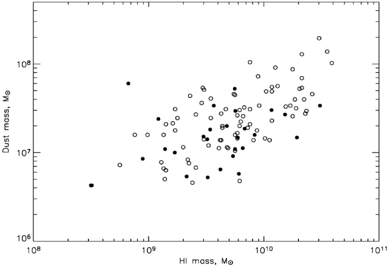


Dunne+2000; SLUGS 104 IRAS BGS.

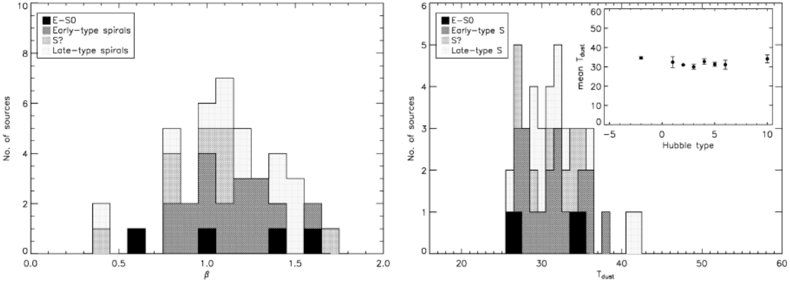


Vlahakis+2005;
filled circles:OS, open circles BGS

Be careful:
Those are single temperature model!

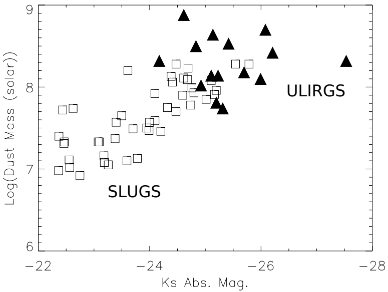
Cold dust along the Hubble sequence

There is no tendency for the changes with Hubble types

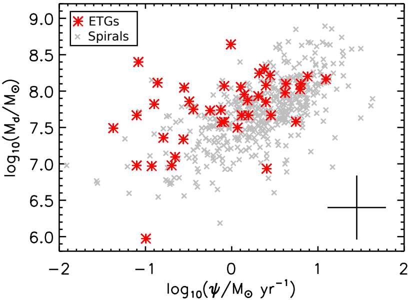


- The distributions of β and T_d fitted in single component model.
- The distributions and the median values of T_c and T_w

Dust difference of various type of galaxies - Mass



Clements+2010

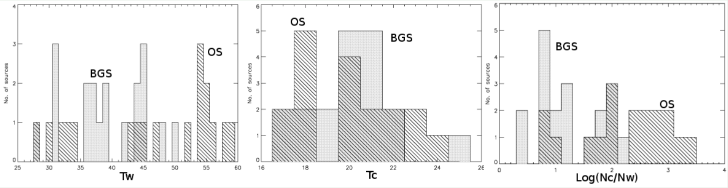


Rowlands+2011

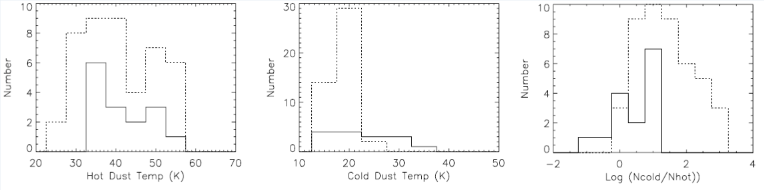
Be careful:
Those are single temperature model!
Lack of the mulit-component analysis

Dust difference of various type of galaxies - Temperature

OS sample and IRS sample, Vlahakis et al.,2005

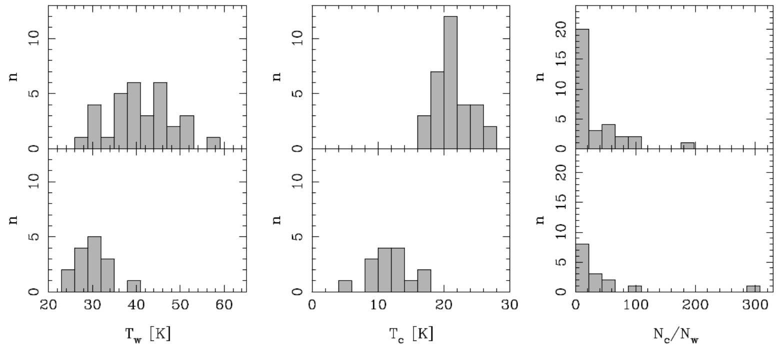


ULIRGS sample and SLUGS sample, Clements et al.,2010



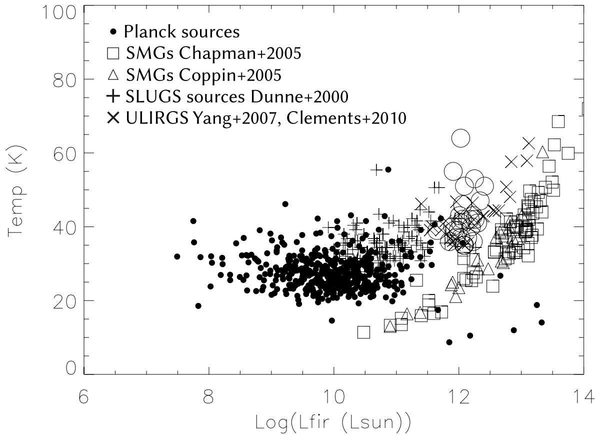
Dust difference of various type of galaxies - Temperature

14 local Spiral galaxies and SLUGS sample,Stevens et al.,2005



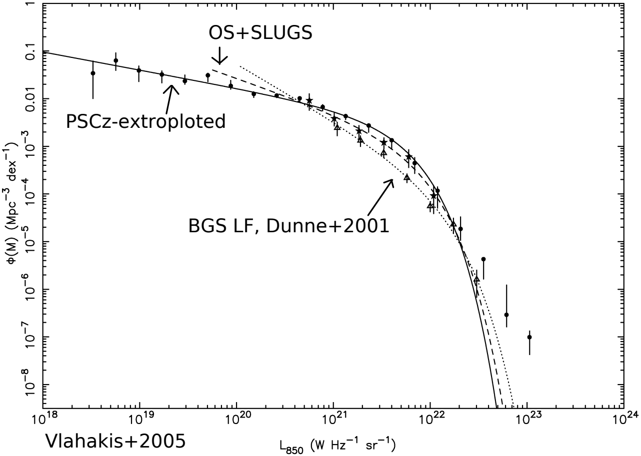
There may be a connection between star-formation activity and T_d.

Luminosity-Temperature Plain



Ade+2011, new results from Planck.

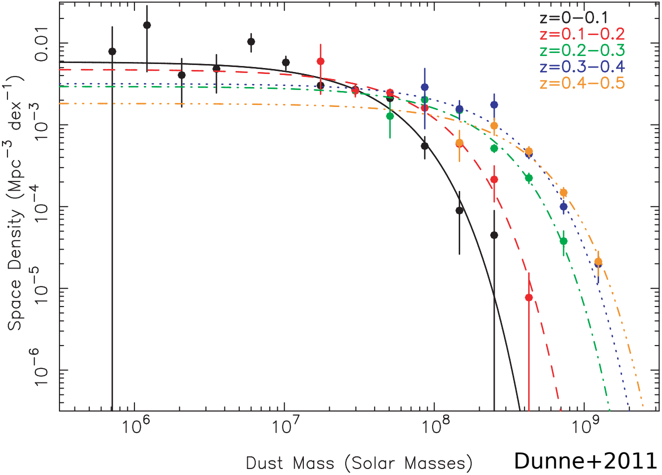
$850\mu m$ Luminosity Function



PSCz-extroploted: $\alpha = -1.38$; OS+SLUGS: $\alpha = -1.71$; SLUGS: $\alpha = -2.18$.

Dust Mass Function

There did exist dust mass evolution. And DMF can help us understand a lot!



Dunne+2011

How do the dust form?

- Budget crisis both in low and high-z:
  - Early-type galaxies (Rowlands+2011)
    Cold dust is too much to be produced!
  - High-z SMGs (Michałowski + 2010)
    Its too early to form so much dust!
- Possible solutions:
  - Our SNe theory needs modified
    (controversial between observation and model: Matsuura+2011; Dunne+2003; Sibthorpe+2009)
  - top-heavy IMF (not enough)
  - grains growth in the ISM
  - inefficient destruction

Summary

- A very cold dust component exists
  - two components model with $\beta = 2$
  - cold dust is extended distributed
  - good dust and gas correlation
  - real situations may be much more complicated
- Cold dust exists in many kinds of galaxies, and we underestimated their amount
  - we face a dust budget crisis
  - there need more study on the dust origin at high-z and the process on dust destruction
- Previous view of the dust is biased by IRAS
  - Herschel(H-ATLAS, HerMES) and Planck(ERCSC) are doing surveys, more inspiring results are coming out!

Future Prospect

- Blind survey is needed with much larger samples!
  - Herschel & SCUBA-2
- We also need a more precise physical model of dust in galaxies, this model is still too simple!
  - Optical Thin, single-T(lack of data) graybody systematically overpredicts observed submm flux (Hayward+2011, use 3D simulation)
- Multiband view of galaxy SED study, using extinction information.

Thank you & Merry Xmas!

(in advance)